Mineral Composition of Swards Containing Forage Chicory

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ABSTRACT

Chicory (*Cichorium intybus* L.), a highly productive forage under midsummer conditions in the eastern USA, often has higher concentrations of minerals relative to grasses and legumes. Low concentrations of minerals in herbage could reduce production efficiency or create metabolic disorders in livestock. Information on the mineral composition of chicory is limited, but it is needed to improve our understanding of nutritive value and inputs required to sustain chicory production, especially where high rates of N are applied. We conducted field experiments for 3 yr on a Ramsey soil (Loamy, siliceous, subactive, mesic Lithic Dystrudept) in southern West Virginia to determine (i) response to increasing fertilizer N and (ii) production of chicory as a component of swards, including grass and legume as a function of clipping frequency. Mineral concentrations and uptake in available herbage generally increased as N rate increased and were influenced by the botanical composition of the sward. As chicory content decreased in the sward, so did mineral concentrations and uptake. Changes in sward composition associated with chicory influenced important mineral ratios such as N/S, Ca/P, and K/(Ca + Mg) cation equivalent ratio that have significant bearing on livestock health and production efficiency. Clipping frequency and N inputs influenced chicory persistence and ultimately the mineral composition of the sward. Active accumulation of minerals indicates the need for high nutrient input to sustain production, especially on soils with marginal fertility. Health problems associated with mineral nutrient concentrations probably would be minimal in livestock grazing swards that include chicory.

Successful chicory production for grazing livestock depends on achieving a balance between vigorous growth and herbage quality (Li et al., 1994). Management factors such as N rate and defoliation frequency affect the nutritive value of chicory as well as the total production, stand density, and sward composition (Jung et al., 1996; Collins and McCoy, 1997; Belesky et al., 1999; Belesky et al., 2000). As an example, pure chicory swards grown in central Pennsylvania averaged 230 g kg^{-1} crude protein (CP) under intensive defoliation and 140 g kg^{-1} CP when managed in an infrequent defoliation regime (Jung et al., 1996). Early season chicory herbage had a very high moisture content (850 g kg^{-1}), which increased as N fertilization increased (Collins and McCoy, 1997). Turner et al. (1999) reported greater in vitro organic matter disappearance (IVOMD) for chicory–orchardgrass (*Dactylis glomerata* L.) mixtures than for either forage alone. Apparently, nutritive value is improved in swards that include chicory; however, the overall breakdown of neutral-detergent fiber was slowed when chicory swards were treated with high amounts of ammonium nitrate (NH_4NO_3) fertilizer.

Information on the mineral composition of chicory is limited, but it is needed to understand the nutritive value of chicory herbage and to identify nutrient inputs that sustain production, especially when high rates of N are applied. Crush and Evans (1990) and Reid et al. (1993) reported that the mineral composition of forage chicory was comparable to or exceeded that of white and red clover (*Trifolium repens* and *T. pratense*, respectively) and perennial ryegrass (*Lolium perenne* L.). Mineral concentrations in chicory met or exceeded recommended dietary mineral requirements of lactating dairy cows (Jung et al., 1996), and because chicory had a relatively high B concentration, fertilization with B might be warranted. Herbage may contain mineral concentrations that theoretically meet livestock requirements, but some portion of the total may not be available because of where and how the mineral element occurs in the plant (Spears, 1994). The relative concentrations or ratios of certain mineral nutrients in diets, such as Ca/P or K/(Ca + Mg), can also affect metabolism or influence the absorption and bioavailability of nutrients to the grazer. The relatively low fiber concentration and high IVOMD and moisture content of chicory (Volesky 1996; Collins and McCoy, 1997; Belesky et al., 1999) suggest that mineral bioavailability should be high.

Herbage is an important means of delivering minerals to grazing livestock in extensive and low-input situations. Mineral deficiencies can depress forage digestibility and herbage intake (Provenza, 1995) and compromise livestock production efficiency, especially in marginal resource situations. One means of ensuring adequate mineral nutrition of the diet is to increase the floristic diversity of a sward (Hasler, 1971). In many cases, floristic diversity is a function of the soil resource (Stout et al., 1977). Baker and Reid (1977) and Reid et al. (1970) reported that mineral concentrations essential to livestock health were present in greater quantities in weeds and legumes than in grasses. Canopy utilization and soil fertility also interact to affect the composition of swards, including those sown to chicory, and ultimately the nutritive value of chicory herbage (Belesky et al., 1999, 2000).

We conducted field experiments to determine the influence of (i) N on pure swards of chicory and (ii) clipping frequency on pure chicory and mixed-species swards containing chicory. Mineral composition was determined on composite herbage samples representing swards ranging from pure chicory to mixtures containing chicory and naturalized cool-season grasses and legumes.

MATERIALS AND METHODS

Site Preparation and Treatments

Two field experiments were conducted for 3 yr (1994–1996) on a gently sloping upland site of Ramsey soil (Loamy, sili-

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Abbreviations: CP, crude protein; DM, dry matter; IVOMD, in vitro organic matter disappearance.

ceous, subactive, mesic Lithic Dystrudept) in southern West Virginia (38° N, 81° W; 850 m above sea level). Temperature and precipitation data collected at the site and long-term means recorded at the National Weather Service Office (National Oceanographic and Atmospheric Administration) located about 5 km west of the experimental sites are presented in Belesky et al. (1999, 2000). Initial soil pH was about 6.6, and there were moderate levels of Bray-1 available P (Olsen and Sommers, 1982) and exchangeable K (ammonium acetate extractable) in the surface 15 cm. Plot areas were prepared by spraying existing vegetation with glyphosate [*N*-(phosphonomethyl) glycine] at 1.19 kg a.i. ha^{-1} in late spring of 1993, roto-tilling the sod to about 10 cm, followed by smoothing and raking to prepare a firm seedbed. No insecticides or herbicides were used once plots were sown.

Experiment 1 was set out as a randomized complete block designed to determine growth and yield response of chicory to fertilizer N application. Details concerning this experiment can be found in Belesky et al. (2000). Plots were broadcast-sown to 'Grasslands Puna' chicory (10 kg ha^{-1} seed) in early June of 1993 and culti-packed to improve seed-to-soil contact. Each plot was 2 by 4 m, and five plots were in each of three replicate blocks. Stands were clipped with a rotary mower once in late summer of 1993 to control weeds and at 6-wk intervals beginning in late spring of 1994 (three harvests) and during four harvests in 1995 and 1996. Nitrogen (35 kg N ha^{-1} as NH_4NO_3) was applied in the establishment year after plants were actively growing (vigorous leaf appearance about 4 wk after sowing). In addition, 80, 150, and 2 kg ha^{-1} of P, K, and B were applied at establishment and in the spring of each subsequent year of the experiment. Nitrogen (NH_4NO_3) was applied in a single dose at rates of 60, 120, 240, or 480 kg ha^{-1} when leaf formation began in mid-April of each year. A control (0 N applied) and each N rate were replicated three times.

Experiment 2 was a randomized complete block design with plots split to address the interaction of clipping frequency × sward composition. Additional details can be found in Belesky et al. (1999). Plots (3 by 5 m) were broadcast-sown in early June of 1993 to Grasslands Puna chicory, Norcen birdsfoot trefoil (*Lotus corniculatus* L.), and 'Hallmark' orchardgrass, creating stands of pure chicory and chicory–orchardgrass and chicory–orchardgrass–trefoil mixtures. Chicory was sown at 10 kg ha^{-1} in pure plots and at 5 kg ha^{-1} in mixtures. Trefoil was sown at 5 kg ha^{-1} and orchardgrass was sown at 15 kg ha^{-1}. Fertilizer (70 and 100 kg ha^{-1} of P and K) was broadcast at seeding. Nitrogen (35 kg N ha^{-1} as NH_4NO_3) was applied in the establishment year after plants were actively growing. Fertilizer (35 kg N ha^{-1} as NH_4NO_3, 80 kg P ha^{-1}, and 150 kg K ha^{-1}) was applied in the spring of each subsequent year of the experiment.

Clipping and sampling were carried out for three consecutive years beginning in 1994. Stands were clipped once (to 5-cm stubble) in late summer of 1993 to control weeds. Plots in Experiment 2 were divided (1.5- by 5-m plots) to accommodate a 3- and 6-wk clipping frequency. The 3-wk frequency was first harvested in late May of each year. The first harvest of the 6-wk clipping frequency coincided with birdsfoot trefoil flowering, and subsequent clips approximated regrowth interval requirements for trefoil.

Sample Collection and Analysis

Sample strips (0.6 by 3.0 m) located in the center of each plot in Experiments 1 and 2 were clipped to a 5-cm residue height with a collection bag equipped rotary mower. Herbage samples were dried at 60°C in a forced-air oven and ground in a cyclone mill to pass a 0.5-mm screen before chemical analyses. Botanical composition of the stands was determined at 6-wk intervals using the point-quadrat method described by Warren-Wilson (1959). Each of 45 contact points in a plot was categorized as chicory, grass [orchardgrass, tall fescue (*Festuca arundinacea* Schreb.), and Kentucky bluegrass (*Poa pratensis* L.)], or legume (includes red and white clover, which occur naturally on the site, and the birdsfoot trefoil that was sown). Weeds (forbs and grasses not specifically listed above) and bare ground were noted but not included in the data analysis because their contribution to total composition was nominal. Details of botanical composition of the swards can be found in Belesky et al. (2000) for Experiment 1 and in Belesky et al. (1999) for Experiment 2.

Herbage concentrations of P, S, Zn, B, Mg, Ca, Cu, and K were obtained by inductively coupled plasma spectroscopy (Model JY 46 P, JY-Horiba, Jobin Yvon Emission Division, Edison, NJ[1]). Ground plant tissue (100 mg) was treated with 1 mL 15.4 *M* HNO_3 and digested by a microwave process. The digestion was done in sealed Teflon-lined digestion vessels (Parr Microwave Acid Digestion Bomb, Parr Instrument Co., Moline, IL). Samples were digested in a conventional microwave (1100 W) as follows: 4 min at 70% power, 2 min at 100% power, and 5 min without power. Digestion vessels were removed from the microwave and allowed to cool. The contents of each cup were rinsed into a 10-mL glass volumetric flask, filtered, combined with 10 μg g^{-1} Y standard, and brought to volume using analytical grade I water. Reference tomato (*Lycopersicon esculentum* L.) leaf tissue (NIST Standard Reference Material SRM 1573a; U.S. Dep. of Commerce, Natl. Inst. of Standards and Technol., Gaithersburg, Maryland) was used to standardize the mineral analyses.

Nitrogen in the 1994 samples was determined by total combustion of the sample on a LECO CHN 600 (LECO Corp., St. Joseph, MI); a Carlo Erba EA1108 CHNS Analyzer (CE-Elantech, Lakewood, NJ) was used for the 1996 samples. Reference tomato leaf tissue analysis showed that N analysis methods gave comparable results. Detailed N data for chicory herbage are presented in Belesky et al. (1999, 2000).

Data from Experiment 1 were analyzed as a randomized complete block design using general linear models (GLM) procedures of SAS (Littell et al., 1991). Univariate procedures were used to evaluate the influence of treatment within N rates (repeated measures for harvest dates) on herbage mineral concentrations. Variances for elements and dry matter yield were heterogeneous for years; consequently, years were analyzed separately. Regression equations were developed using orthogonal polynomial contrasts for the influence of N rate on specific elements. Data from Experiment 2 were analyzed as a split-plot using SAS-GLM procedures. Univariate procedures were applied to evaluate the influence of clipping frequency within sward composition (repeated measures for harvest dates). The variances for dry matter yields in Experiment 2 were heterogeneous for years; consequently, years were analyzed separately.

RESULTS AND DISCUSSION

Mineral concentrations reported here reflect available herbage as a function of botanical composition over time: In Experiment 2, varied botanical composition was intentional, but in Experiment 1, it was not. Consequently, concentrations are a function of plant maturity

[1] Trade or proprietary names are used for the convenience of the reader and do not imply endorsement by USDA-ARS over comparable products.

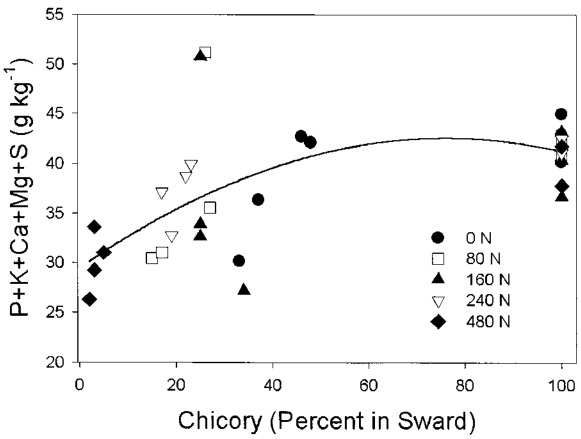

Fig. 1. Macronutrient (P + K + Ca + Mg + S) concentration (g kg^{-1}) in available herbage as a function of N fertilizer (kg ha^{-1}) and chicory in the sward. Macronutrient concentration = 0.32 (% chicory)^2 − 1.78 × 10^{-2} (% chicory) + 31.07; R^2 = 0.59.

and age as well as changing botanical composition of the sward. This relationship is shown in Fig. 1 where the amount of chicory in the sward was a function of time and N rate and influenced the total quantity of macronutrients. As the proportion of chicory declined, so did total mineral content. Briefly, in Experiment 1, the sward in 1994 was virtually pure chicory, regardless of N rate. By 1996, the contribution of chicory to the sward was much less and ranged from 15% at 480 kg N ha^{-1} to about 40% when no N was applied. The loss of chicory was compensated by an increase in grasses. Detailed botanical composition data are reported in Belesky et al. (2000). In Experiment 2, we established swards differing in species composition. Chicory declined as a component of the sward with time, regardless of clipping frequency and initial sward composition. Chicory represented about 30% of the herbage remaining in the sward after 3 yr in Experiment 2, which agrees with Kunelius and MacRae (1999) for grass–legume–chicory mixtures grown in Atlantic Canada. Botanical details of Experiment 2 are reported in Belesky et al. (1999).

Macronutrient Composition

The influence of treatments, i.e., N rate in Experiment 1 (Table 1) or sward composition in Experiment 2 (Table 2) and time on the P and S of herbage generated in Experiments 1 and 2 are discussed in detail; in general, other mineral nutrients were influenced similarly. Increasing N rate and advancing harvest date generally led to increased concentrations in 1994 when swards were mostly chicory. By 1996, when chicory content ranged from 15 to 40% of the sward depending on the amount of N applied (Belesky et al., 2000), increasing the N rate decreased the P, S, Mg, Ca, and K concentrations (Table 3). Concentrations in herbage tended to increase with successive harvests during 1996 (data not shown).

Phosphorus concentrations of herbage in Experiment 1 declined (23% from 4.4–3.4 g kg^{-1} in 1994 and 27% from 3.7–2.7 g kg^{-1} in 1996) as N was increased from 0 to 480 kg ha^{-1} (Table 3). The decline in P with higher N rates probably arose from dilution caused by greater tissue mass. Concentrations were less in 1996 than in 1994, which could be attributed to a combination of changing sward composition (Belesky et al., 2000) and depletion of soil P. In 1994, when chicory was the predominant component of canopies, P uptake increased 18% (from 14.6–18.7 kg P ha^{-1}) as N increased from 0 to 480 kg ha^{-1}. Phosphorus uptake declined 23% (from 23.9–16.7 kg P ha^{-1} at 0–480 kg N ha^{-1}) in 1996 when chicory in the sward was less (data not shown).

Sward composition, harvest frequency, and interaction of harvest frequency × time during the growing season had significant but small effects on P for herbage collected in 1994 in Experiment 2 (Table 2). In 1994, swards that were clipped at 3-wk intervals had 30% less P uptake than those clipped at 6-wk intervals. Harvest frequency effects are probably attributable to the amount of chicory present in the sward as well as total herbage production (Belesky et al., 1999). Phosphorus uptake was significantly influenced by the interaction of harvest frequency × harvest date (Table 2), probably as a function of the influence on sward composition (Belesky et al., 1999). Phosphorus concentrations met or exceeded the requirements of 1.7 to 3.9 g kg^{-1} for beef cattle in various physiological stages of production (NRC, 1996) as well as the recommended range of 1.6 to 3.8 g kg^{-1} for sheep (NRC, 1985).

Sulfur concentrations ranged between 2 and 5 g kg^{-1} dry matter (DM) in each year of Experiment 1 and declined as N rate increased (Table 2). Sulfur concentrations were similar in swards of pure chicory, chicory–orchardgrass, and chicory–orchardgrass–trefoil managed as hay; they ranged from 3 to 6 g kg^{-1} DM over the 1994 growing season but averaged 1.5 g kg^{-1} DM by

Table 1. Analysis of variance and significant effects of N rate and harvest date on the mineral concentration (C) and mineral yield (Y) of chicory in 1994 and 1996.

			P		K		Ca		Mg		S	
Factor	df		1994	1996	1994	1996	1994	1996	1994	1996	1994	1996
N rate (N)	4	C	**	**	**	**	**	**	*	**	**	**
		Y	**	**	**	**	**	**	**	**	**	**
Harvest date (HD)	2 (3)†	C	**	**	**	**	*	**	**	**	NS	**
		Y	**	**	**	**	**	**	**	**	**	**
N × HD	8 (12)	C	NS	NS	**	NS	**	NS	NS	NS	NS	NS
		Y	*	*	NS	NS	*	**	**	*	*	*

* Significant at the 0.05 level.
** Significant at the 0.01 level.
† Value in parentheses is df for 1996. 1994 error df = 20; 1996 error df = 29.

Table 2. Analysis of variance and significant effects of harvest frequency, harvest date, and sward composition on mineral concentration in herbage in 1994 and 1996.

		P		K		Ca		Mg		S	
Factor	df†	1994	1996	1994	1996	1994	1996	1994	1996	1994	1996
Harvest frequency (HF)	1	**	**	NS	*	**	NS	**	NS	NS	NS
Harvest date (HD)	3	**	**	**	**	**	**	**	**	**	**
HF × HD	3	**	**	**	*	**	NS	**	NS	*	*
Sward composition (SC)	2	*	NS	NS	NS	*	NS	NS	*	NS	NS
HF × SC	2	NS	NS	NS	NS	NS	*	NS	NS	NS	NS
HF × HD × SC	12	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

* Significant at the 0.05 level.
** Significant at the 0.01 level.
† 1994 error df = 42; 1996 error df = 41.

1996 when the amount of chicory in the sward declined (Table 4). Sulfur uptake in 1996 declined 38% as N was increased from 0 to 480 kg ha^{-1} (data not shown). The decrease in S concentration and uptake may be related to changes in botanical composition of the sward (Belesky et al., 1999) or changes in soil S availability. Herbage S uptake in swards that were clipped frequently was 52% less than that in herbage managed as hay. Sulfur concentrations (Table 4) in swards containing chicory, typified by the sward composition found in 1994, exceeded the requirements of 1.7 to 3.9 g kg^{-1} for beef cattle (NRC, 1996) and generally met the recommended range of 1.4 to 2.6 g kg^{-1} for sheep (NRC, 1985). Swards with low amounts of chicory are likely to be marginal in terms of meeting mineral nutrient requirements of livestock.

Macronutrient Relationships

Sulfur and minerals such as Ca and Mg in herbage may enhance forage quality by improving fiber digestion (Spears, 1994). Although fiber concentrations in chicory are low compared with those of common cool-season grasses and legumes (Collins and McCoy, 1997), ample mineral concentrations in chicory could lead to overall improvements in ruminant utilization of forage mixtures that include chicory. Regardless of actual concentrations, the value of mineral nutrients in forage may have a greater impact when considered relative to other elements. Minerals supplied by forages in livestock diets are influenced by factors such as forage type, stage of maturity, management, and localization in plant tissue. Herbage intake is also an important determinant of mineral adequacy in animal diets (Spears, 1994). In many situations, plants could have high concentrations of certain minerals but contain compounds (e.g., phytates) that interfere with absorption, and thus decrease the biological value (O'Dell, 1984) of mineral nutrients in the diet. Interactions and ratios among minerals should be considered when defining needs to support superior livestock health, growth, and production. Several of the more important nutritional relationships are presented here.

Nitrogen/Sulfur

The N/S ratios in Experiment 1 increased as fertilizer N application rate increased in 1994 and declined with increasing N in 1996. The N/S ratio of pure chicory (represented by 1994 data) ranged from 4.4 when no N was applied to about 12.6 at 480 kg N ha^{-1} and increased linearly as N rate increased (Fig. 2). Ratios in 1996 represent typical cool-season grass and legume swards with response to N rate confounded by changing botanical composition, specifically a decline in the amount of chicory. The N/S ratios for swards containing chicory

Table 3. The influence of N rate (0, 80, 160, 240, and 480 kg ha^{-1}) in Experiment 1 on the macro (P, K, Ca, Mg, S) and micro (Cu, Zn, B) nutrient concentrations in chicory-containing swards in 1994 and 1996. Values are means and ranges (in parentheses) across the growing season.

	1994					1996				
	0	80	160	240	480	0	80	160	240	480
					g kg^{-1}					
P	4.4	4.1	4.4	3.2	3.4	3.7	3.6	3.2	2.6	2.7
	(3.7–5.2)	(3.7–4.6)	(3.8–4.9)	(2.5–3.8)	(2.2–4.0)	(2.1–4.9)	(2.3–4.6)	(1.8–3.9)	(2.0–3.0)	(1.6–3.5)
K	17.9	17.4	16.5	18.4	13.9	24.6	23.5	19.9	18.8	17.1
	(17.5–18.4)	(15.4–18.8)	(16.0–17.0)	(15.7–21.0)	(8.0–19.9)	(19.8–32.0)	(18.3–28.9)	(17.0–25.5)	(16.9–21.3)	(14.3–21.3)
Ca	14.7	13.8	13.7	12.0	10.6	10.8	9.3	8.2	6.8	5.7
	(13.5–15.6)	(12.1–14.8)	(12.0–15.8)	(11.1–12.8)	(8.2–12.1)	(5.8–16.3)	(4.5–12.8)	(3.9–10.2)	(4.0–8.4)	(2.6–7.6)
Mg	5.8	6.2	7.2	6.5	6.5	3.7	3.3	3.7	3.2	2.8
	(5.1–6.3)	(5.7–7.1)	(6.3–8.3)	(5.7–8.1)	(5.3–8.3)	(2.0–4.9)	(1.9–4.0)	(2.1–4.6)	(2.3–3.6)	(1.5–3.5)
S	4.7	4.3	4.0	3.0	2.7	3.0	2.6	2.5	2.2	2.0
	(3.9–5.7)	(3.6–4.8)	(3.4–4.4)	(2.8–3.3)	(2.1–3.7)	(1.4–4.3)	(1.4–3.2)	(1.3–3.1)	(1.5–2.8)	(1.0–2.6)
					mg kg^{-1}					
Cu	57	50	44	51	62	17	17	19	22	18
	(37–92)	(37–665)	(31–64)	(41–61)	(55–71)	(6–25)	(6–24)	(8–24)	(8–36)	(7–23)
Zn	71	75	73	68	67	53	55	51	52	48
	(62–77)	(67–82)	(70–76)	(66–69)	(62–69)	(36–67)	(41–78)	(35–69)	(41–66)	(31–74)
B	27	24	27	25	22	24	21	18	14	11
	(24–29)	(21–26)	(23–30)	(21–29)	(13–28)	(15–23)	(12–29)	(12–26)	(11–16)	(5–19)

Table 4. The influence of sward composition and harvest frequency (wk) on the macro (P, K, Ca, Mg, S) and micro (Cu, Zn B) concentrations in herbage in 1994 and 1996. Values are means and ranges (in parentheses) across the growing season in Experiment 2.

		1994			1996		
		C†	C–O‡	C–O–T§	C	C–O	C–O–T
	wk			g kg^{-1}			
P	3	4.6 (3.5–5.6)	4.8 (4.0–5.8)	4.9 (3.8–6.0)	2.2 (2.1–2.3)	2.1 (1.9–2.2)	2.2 (2.2–2.2)
	6	4.5 (3.1–5.2)	4.4 (2.8–5.5)	4.7 (2.9–5.7)	1.9 (1.6–2.4)	1.9 (1.5–2.6)	2.1 (1.4–2.4)
K	3	20.1 (16.8–25.9)	20.3 (15.1–28.1)	19.9 (14.5–27.8)	13.5 (10.7–18.0)	13.1 (11.0–17.0)	13.5 (10.7–19.3)
	6	21.3 (18.5–24.7)	20.9 (18.3–24.8)	19.9 (22.9–17.1)	12.1 (10.1–15.4)	11.9 (9.4–14.1)	12.9 (10.4–16.0)
Ca	3	15.0 (13.5–16.6)	14.1 (11.9–17.4)	13.4 (11.4–15.4)	3.7 (3.3–4.0)	3.9 (3.3–4.8)	3.5 (3.2–3.8)
	6	15.7 (14.7–17.9)	16.0 (14.7–18.6)	15.1 (12.3–16.9)	3.1 (2.3–3.7)	3.4 (2.6–4.3)	3.8 (2.9–5.3)
Mg	3	5.2 (4.3–6.0)	5.4 (4.6–6.4)	5.5 (4.6–6.3)	1.8 (1.7–1.8)	1.9 (1.7–2.0)	1.9 (1.8–2.0)
	6	5.6 (4.6–6.1)	5.8 (4.6–6.3)	5.6 (4.0–6.4)	1.7 (1.3–2.0)	1.8 (1.5–2.1)	2.0 (1.5–2.5)
S	3	4.8 (3.5–5.8)	4.4 (2.9–5.7)	4.8 (2.7–6.4)	1.6 (1.5–1.8)	1.6 (1.4–1.8)	1.6 (1.5–1.7)
	6	4.6 (3.3–5.8)	4.4 (2.9–5.7)	4.8 (2.7–6.4)	1.4 (1.0–1.7)	1.5 (0.9–1.9)	1.5 (1.0–2.0)
				mg kg^{-1}			
Cu	3	34 (23–59)	31 (21–53)	30 (22–44)	8 (7–9)	7 (6–8)	7 (7–8)
	6	31 (28–35)	28 (24–32)	25 (23–27)	7 (5–9)	7 (5–9)	8 (5–10)
Zn	3	64 (49–79)	61 (48–79)	60 (45–73)	20 (18–21)	21 (17–28)	19 (17–20)
	6	62 (53–68)	60 (47–75)	60 (45–69)	22 (15–37)	18 (14–21)	20 (15–25)
B	3	19 (15–22)	18 (14–22)	18 (14–22)	9 (6–13)	9 (6–12)	9 (5–14)
	6	19 (18–22)	18 (17–19)	20 (17–22)	6 (4–8)	7 (4–9)	8 (6–13)

† C, chicory.
‡ C–O, chicory–orchardgrass.
§ C–O–T, chicory–orchardgrass–trefoil.

are within the recommended range for sheep (NRC, 1985) and cattle (NRC, 1996) and appear suitable for extensive production situations. Optimal N/S ratios in livestock diets are reported as 11:1 for sheep and 15:1 for cattle (Kincaid, 1988). Increasing levels of dietary S influenced dietary Cu, Zn, and Se availability to sheep (Suttle, 1974).

The N/S ratios of swards clipped at 3- or 6-wk intervals in Experiment 2, regardless of desired sward composition, were <10 in 1994 while ratios generally ranged from 15 to 25 in 1996 (Fig. 3). Sulfur concentrations were 3 to 4 times greater in 1994 than in 1996, regardless of sward composition, while N concentrations were similar in both years (see Belesky et al., 2000).

Calcium/Phosphorus

Calcium and P are considered together because of their importance in preventing metabolic function disorders in livestock. Forages generally contain adequate concentrations of Ca for sheep and beef cattle (Spears, 1994) and usually do not lead to health problems that are related to nutrition, but Ca disorders can involve other minerals such as P and Zn. Low P in forages could be a concern in extensively managed grazing situations, especially under drought conditions. Urinary calculi may occur when diets contain more than twice the dietary P requirement (Emerick, 1988). Maintaining dietary Ca/P ratios in the range of 1.5:2 to 2:1 reduces functional disorders related to Ca and P (Underwood, 1966).

The Ca/P ratios averaged 3.3 ± 0.4 in 1994 (when chicory was dominant) and 2.6 ± 0.3 in 1996 (when canopies had substantially less chicory) and were not affected by N rate. The Ca/P ratios in pure chicory and

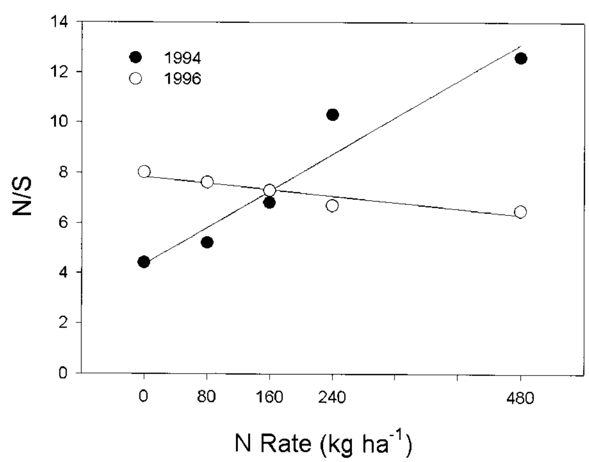

Fig. 2. Nitrogen/S ratios as a function of N rate in Experiment 1. In 1994, N/S = 0.02 (N rate) + 4.35; r^2 = 0.93. In 1996, N/S = −0.003 (N rate) + 7.82; r^2 = 0.87.

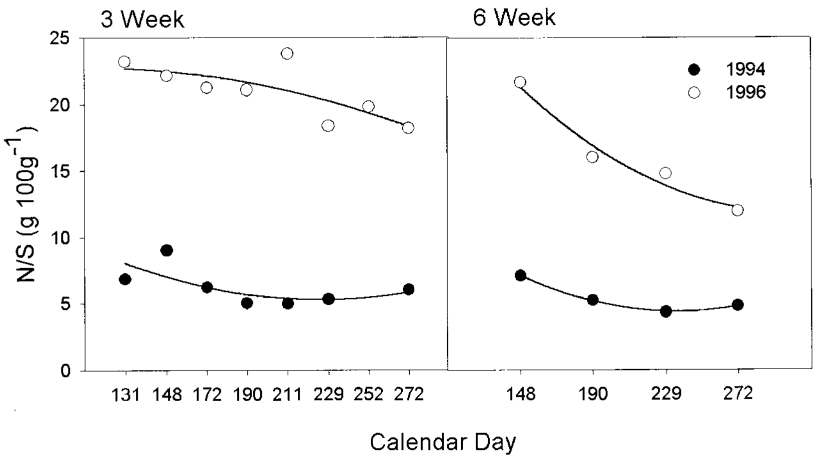

Fig. 3. Nitrogen/S ratios in Experiment 2 as a function of harvest frequency and time (d) over the growing season in 1994 for 3-wk [N/S = 3.20×10^{-4} $(d)^2 - 1.43 \times 10^{-1}$ (d) + 21.34; R^2 = 0.54] and 6-wk [N/S = 3.40×10^{-4} $(d)^2 - 1.6 \times 10^{-1}$ (d) + 23.48; R^2 = 0.99] clipping intervals; and in 1996 for 3-wk [N/S = 7.0×10^{-5} $(d)^2 - 5.88 \times 10^{-2}$ (d) + 29.77; R^2 = 0.89] and 6-wk [N/S = 4.10×10^{-4} $(d)^2 - 2.46 \times 10^{-1}$ (d) + 48.77; R^2 = 0.97] clipping intervals.

mixtures containing chicory were similar to those found in grass–legume hays (Stout et al., 1977). Ratios for pure chicory were 15% greater than for mixed swards when no N was applied and were 54% greater in pure chicory swards than in mixed swards when 480 kg N ha^{-1} was applied. Herbage in Experiments 1 and 2 had relatively high Ca concentrations and average P concentrations. Calcium concentrations were as high as 1.5 g kg^{-1} DM and were greatest at the lowest N levels in 1994 and 1996 (data not shown).

The Ca/P ratios in herbage generated in Experiment 2 averaged ≥3:1 in 1994 and were <2:1 by 1996 (Fig. 4). The ratios were a product of greater concentrations of Ca combined with lesser amounts of P in the tissue. Ratios were greater when swards were clipped at 6-wk rather than 3-wk intervals in 1994 and reflect the contribution made by chicory to the sward. By 1996, clipping frequency had minimal influence on Ca/P ratio.

Potassium/(Calcium + Magnesium)

Magnesium concentrations exceeded the 2 g Mg kg^{-1} recommended to avoid the metabolic disorder, grass

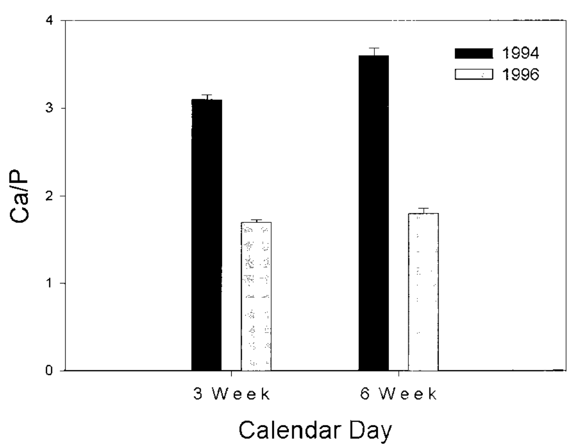

Fig. 4. Calcium/P ratios in 1994 and 1996 as a function of sward composition and harvest frequency in Experiment 2. Bars at the top of each column are the standard error of the mean.

tetany (Mayland and Cheeke, 1995), in Experiment 1 and in 1994 of Experiment 2 when swards were dominated by chicory. Magnesium concentrations are important but must be considered in relation to K and Ca in herbage. Generally, K/(Ca + Mg) ratios in excess of 2.2 (milliequivalent cation basis) can precipitate grass tetany, especially in lactating dairy cattle (Grunes and Welch, 1989). The ratio was <2.2 regardless of clipping frequency or sward composition (Fig. 5). The ratio tended to decline as the growing season progressed. The loss of chicory from the sward by 1996 was compensated by an increase in grasses, and as a consequence, led to lower concentrations of Mg and greater concentrations of K in available herbage. Grunes and Welch (1989) present a detailed account of the likelihood of grass tetany occurrence as a function of changes in the nature of available forage on-offer (e.g., botanical composition, age, and nutritive value). The Mg requirement of growing sheep and cattle is low [1–2 g Mg (kg DM^{-1})]. However, lactating animals have a higher Mg requirement. Other nutritive value components of herbage such as available energy, organic acids, N, and especially K affect Mg absorption and retention in the animal (Mayland and Cheeke, 1995) to influence the requirement for and utilization of Mg.

Micronutrients

Copper and Zn concentrations in available herbage in Experiment 1 were greater than the mean concentrations reported for cool-season grasses (Mayland and Wilkinson, 1996) and orchardgrass (Jung et al., 1996). Copper concentrations were not influenced by N rate. Both Cu and Zn decreased with time in Experiment 1 (Table 2). The Cu concentrations in available herbage declined by 64% from 53 ± 7 mg kg^{-1} in 1994 to 19 ± 2 mg kg^{-1} in 1996. Zinc concentrations declined by 27% from 71 ± 3 mg kg^{-1} in 1994 to 52 ± 2 mg kg^{-1} in 1996. The Cu and Zn yields increased by 90% as N application increased from 0 to 480 kg ha^{-1} in 1994, probably as a function of increasing chicory herbage production and

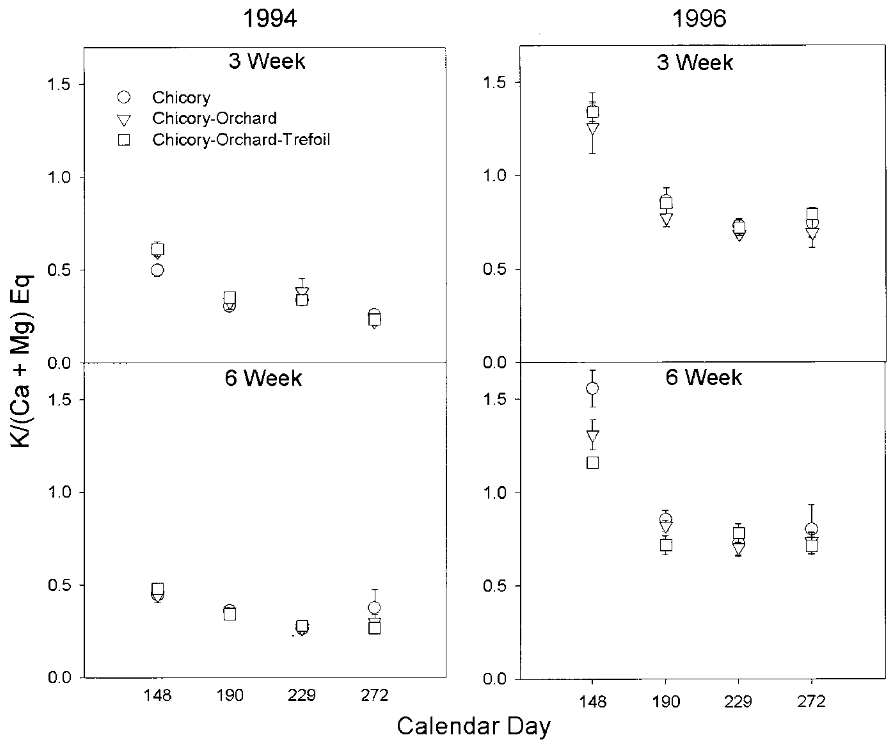

Fig. 5. The relationship of K/(Ca + Mg) on an equivalent basis in 1994 and 1996 as a function of sward composition and harvest frequency in Experiment 2.

unchanging Zn concentrations, but yields were constant or decreased slightly with increased N application in 1996 (data not shown). The loss of chicory and the increase in grasses in the sward by 1996 probably contributed to decline in Zn yield as N application rate was increased.

The Cu concentrations in herbage collected in Experiment 2 (Table 4) were within the average range for herbage mineral concentrations reported by Mayland and Wilkinson (1996); Cu concentrations were slightly greater (14%) in herbage clipped at 3-wk rather than 6-wk intervals and were less in swards with less chicory in 1994. Herbage Cu concentrations were 75% less in 1996 (7 mg kg^{-1}) than in 1994 (30 mg kg^{-1}) but still met or exceeded recommended requirements for sheep (NRC, 1985) and beef cattle (NRC, 1996). As sward composition changed and chicory plants matured, Cu and Zn concentrations declined in available herbage.

Boron concentrations in Experiment 1 were not influenced by N rate in 1994 and averaged 25 $\pm$ 2 mg kg^{-1}. In 1996, B concentrations declined by 50% from 24 to 11 mg kg^{-1}, as N rate increased from 0 to 480 kg ha^{-1}, reflecting mineral composition of swards dominated by grasses rather than chicory. The yield of B in available herbage increased in 1994 as a function of chicory response to N, whereas in 1996, B yield declined as N rate increased, reflecting the strong N response of grasses that contain much less B than does chicory (Hare et al., 1987). Boron concentrations in our experiments were less than those reported for chicory by Jung et al. (1996).

Our results agree with earlier reports noting that mineral concentrations in chicory exceeded those found in grasses and legumes (Hare et al., 1987; Crush and Evans, 1990; Jung et al., 1996; Barry, 1998) and with those reported by Jung et al. (1996) for chicory grown in central Pennsylvania. The influence of N on herbage production and the resultant impact on nutrient composition and mineral yield in herbage are important considerations when developing management practices for forages. Sallette and Huché (1989) showed that N and mineral contents were related primarily as a function of dilution as the forage crop grew. Greater amounts of herbage accumulation often led to dilution of minerals (lower concentrations). If the soil supply of nutrients is not limiting, uptake may actually increase with increasing amounts of N, depending on the growth requirements and accumulation ability of the plant. Experiments are underway to identify mechanisms of nutrient acquisition in chicory. In terms of production management, accumulation of mineral nutrients indicates the need for nutrient input to sustain production, especially on soils with marginal fertility. Health problems of grazing livestock that are associated with mineral composition of swards containing chicory probably would be minimal.

ACKNOWLEDGMENTS

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ERRATA

Forecasting Spring Wheat Yield Using Time Series Analysis: A Case Study for the Canadian Prairies

Vijendra Kumar Boken; Agron. J. 92:1047–1053 (2000).

We wish to report an error that occurred on page 1047 of the above paper, which appeared in the November–December 2000 issue.

On the bottom of the page, in the author–paper documentation footnote, the author's address at the time of research was missing. The footnote should have read, "Dep. of Geography, Univ. of North Dakota, Grand Forks, ND 58202–9020. Current address: Dep. of Geography, Southwest Texas State Univ., San Marcos, TX 78666–4616. Received 9 Aug. 1998 (vb12@swt.edu)." We apologize for any confusion.